On-orbit defocus assessment of satellite cameras using neural network

Ph. Déliot & D. Léger

JACIE 2011

ONERA
THE FRENCH AEROSPACE LAB

retour sur innovation

INTRODUCTION

- Main purpose : Achieving the best focus adjustment
  - To obtain best image quality
  - to check the performances during commissioning period
- Defocus is the first optical parameter to correct
  - Defocus is due to launch vibrations, thermo-elastic effects, desorption…
  - Must be corrected before MTF assessment
- On-orbit conditions, during commissioning period
  - Method should be short in time
  - Method should have few programming constraints

OVERVIEW of defocus assessment methods

Reference method (SPOT):

Comparison with another on-board instrument

- Both cameras image the same landscape
- One is used as a reference
- Focusing mechanism of the other is moved
- The ratio of image spectra is calculated
- The vertex of a defocus model gives the best focus

Alternative method

Use of ground target: direct MTF assessment

These methods work well but require a reference instrument or a specific acquisition (target).

Main features of the Neural Network defocus assessment

- Neural Network (NN) defocus assessment method

  √ This method **does not require any reference** (target, instrument, image, etc…)

  √ It uses on-orbit images with no very “specific” landscapes

  √ It measures the defocus in different parts of image and according to the row or column direction

  √ It offers a redundancy with other methods

  ! It needs several images covering a large range of focusing mechanism position (typically 10)

Neural Network defocus assessment

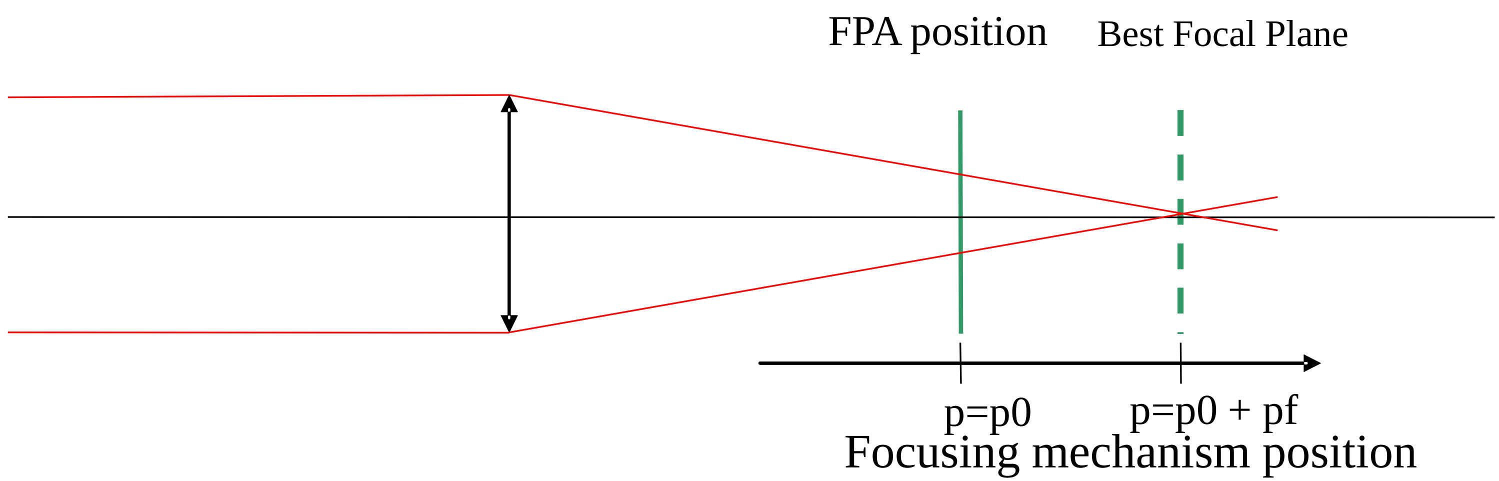
HYPOTHESIS

The modification of an image quality criterion (defocus) leads to measurable effects on the image.

MODELLING

Input: Samples, extracted from the image, can be represented by a vector composed of features that are sensitive to defocus.

Output: We use the value related to the focusing mechanism position.



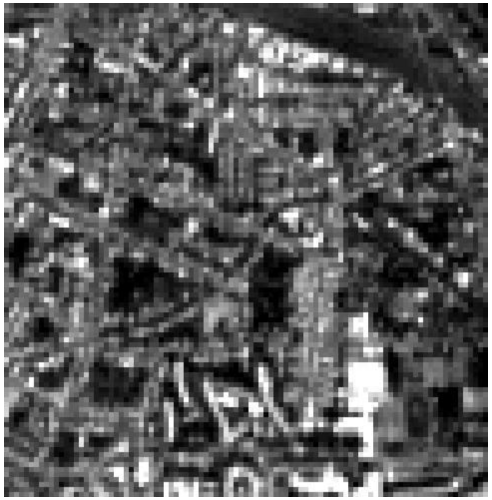
IMPLEMENTATION

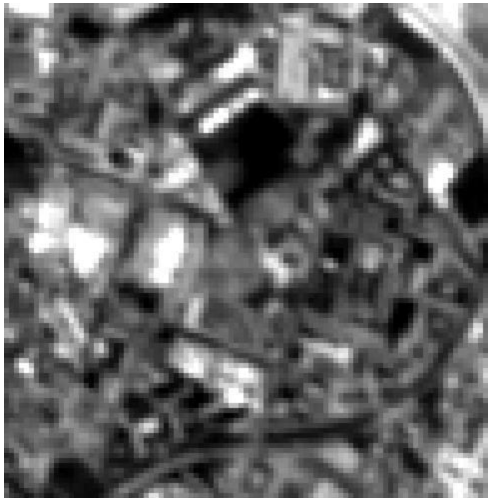
→ Two methods have been developed using feed forward neural network.

→ Many samples with high frequency content are needed from images taken at different focus mechanism positions to train the NN

Data and pre-processing needed for assessment

- Images at different focus mechanism positions
- Urban zones are preferred (high spatial frequency)
- Cutting-out from images to achieve 128x128 pixels images
- Computing of small image features





Examples of SPOT2 128x128 images (p0, p0+8, p0+12)

The most important step: defining features

- FFT mean calculated on different adjacent frequency intervals :

(1) $$S_{mean\_col}([f_{\min}; f_{\max}]) = \sum_{u \in [0; fe]} \left[\sum_{v \in [f_{\min}; f_{\max}]} |FFT(image)(u,v)| \right]$$

- variogram for short inter-pixel distance (h = 1, 2, 3 and 4 pixels) :

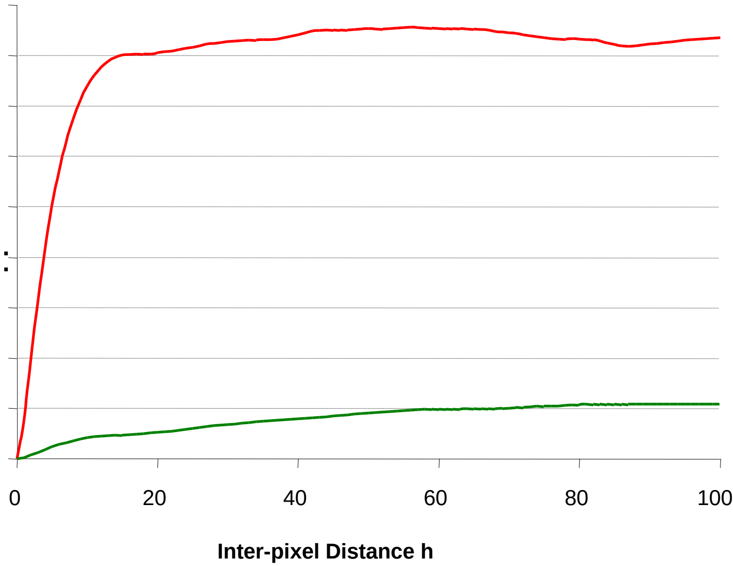
(2) $$\gamma\_col(h) = \frac{1}{2} \cdot E\left(\left| image_{i,j+h} - image_{i,j} \right|^2 \right)$$

- Parameters a, b and c derived from the polynomial model (degree = 2) of the variogram in a logarithm representation

(3) $$\gamma(h) = e^c h^b e^{a \ln(h)^2}$$

- moments of the image : mean, variance, kurtosis and skewness

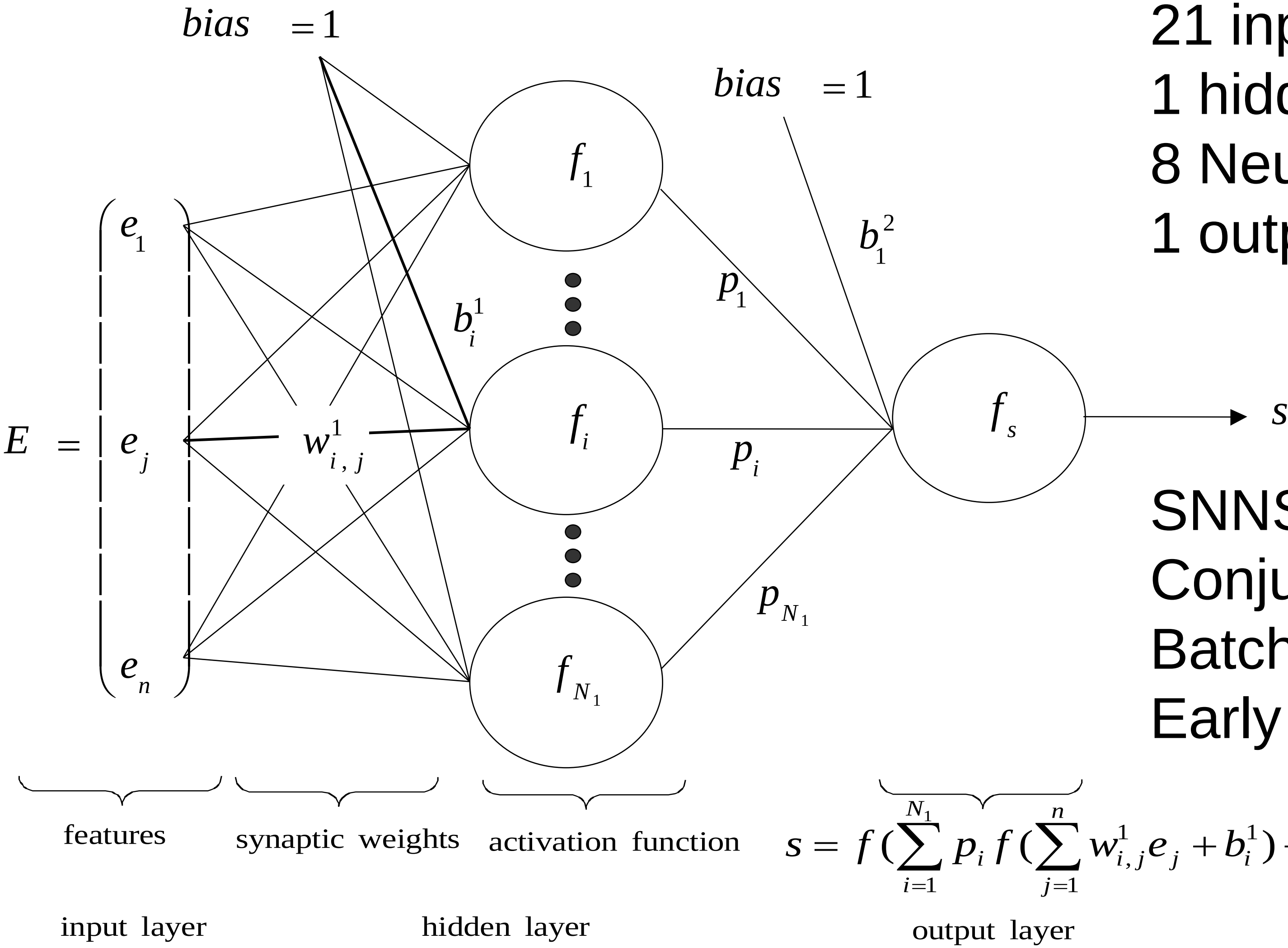
variogram



→ 21 features

Theses features can be designed for column and row direction

Feed forward Neural Networks: Multilayer Perceptron



$$s = f\left(\sum_{i=1}^{N_1} p_i\, f\left(\sum_{j=1}^{n} w^1_{i,j} e_j + b^1_i\right) + b^2_1\right)$$

21 inputs
1 hidden layer
8 Neurons
1 output

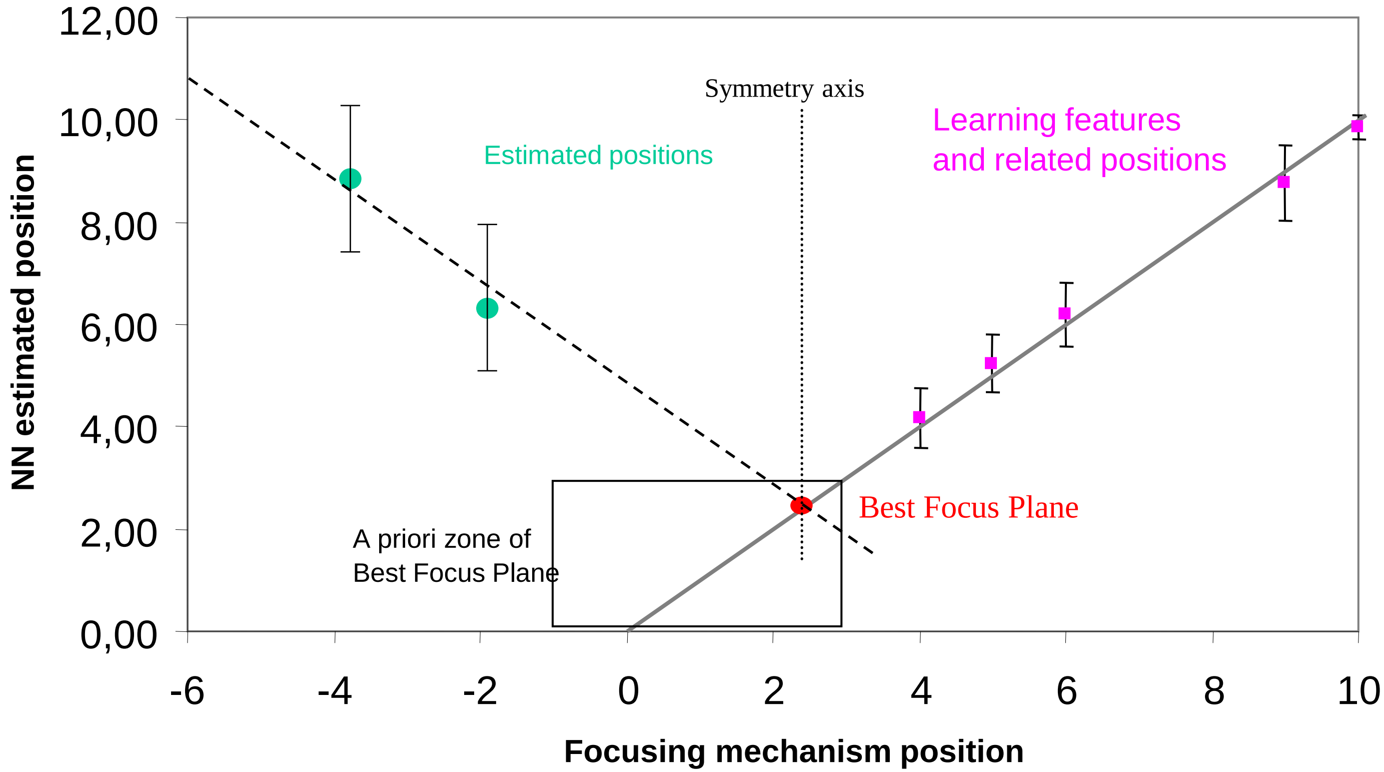
SNNS4.2 software
Conjugate Gradient
Batch mode
Early stopping

Focus Assessment NN Method using symmetry

Hypothesis :

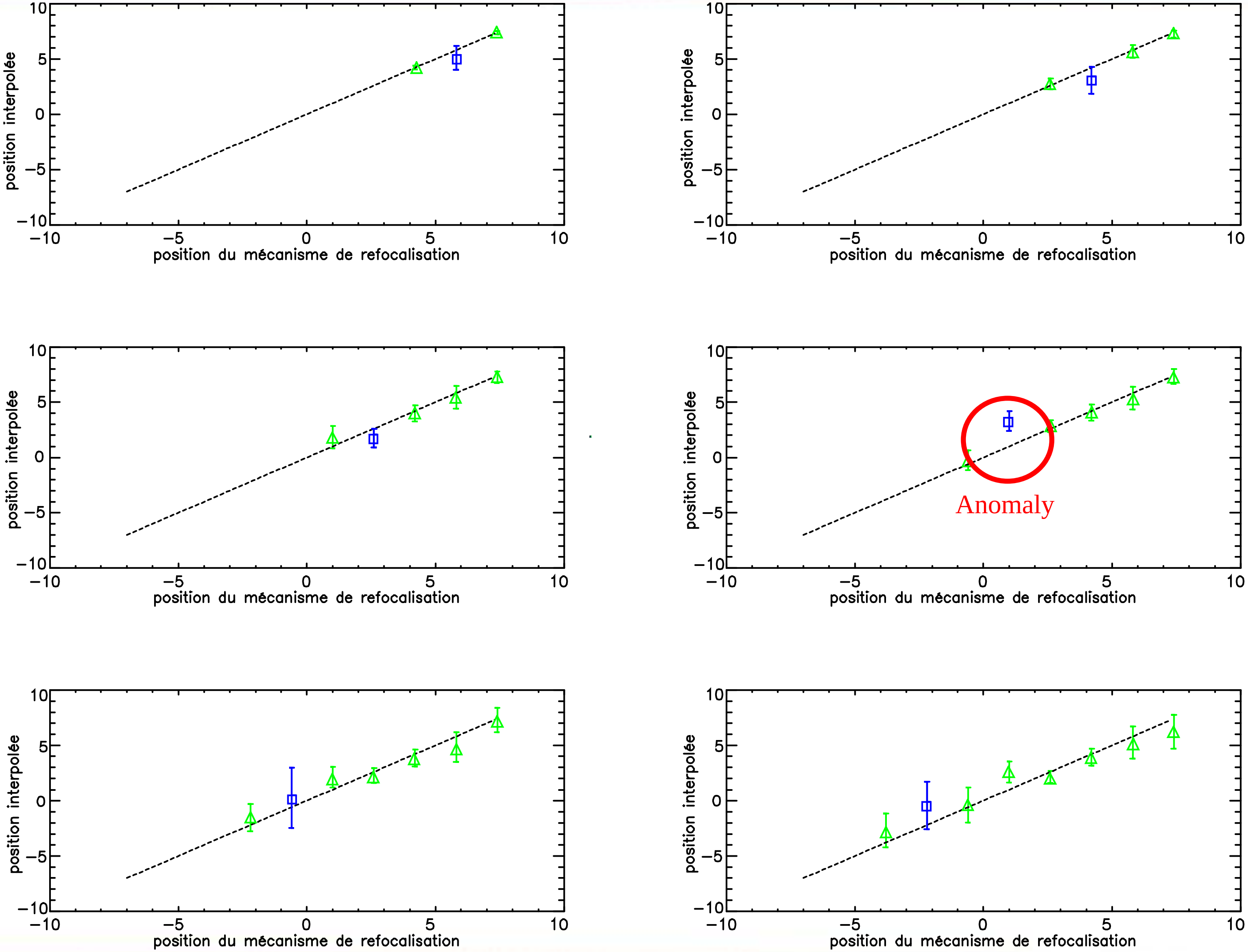
1] Defocusing effects are symmetric

2] We know roughly the zone where to find the Best Focus Plane (BFP)



How defining the BFP zone ? Visual assessment or …

determining the BFP zone using “bad extrapolation detection”



Procedure and test for defocus assessment

Procedure

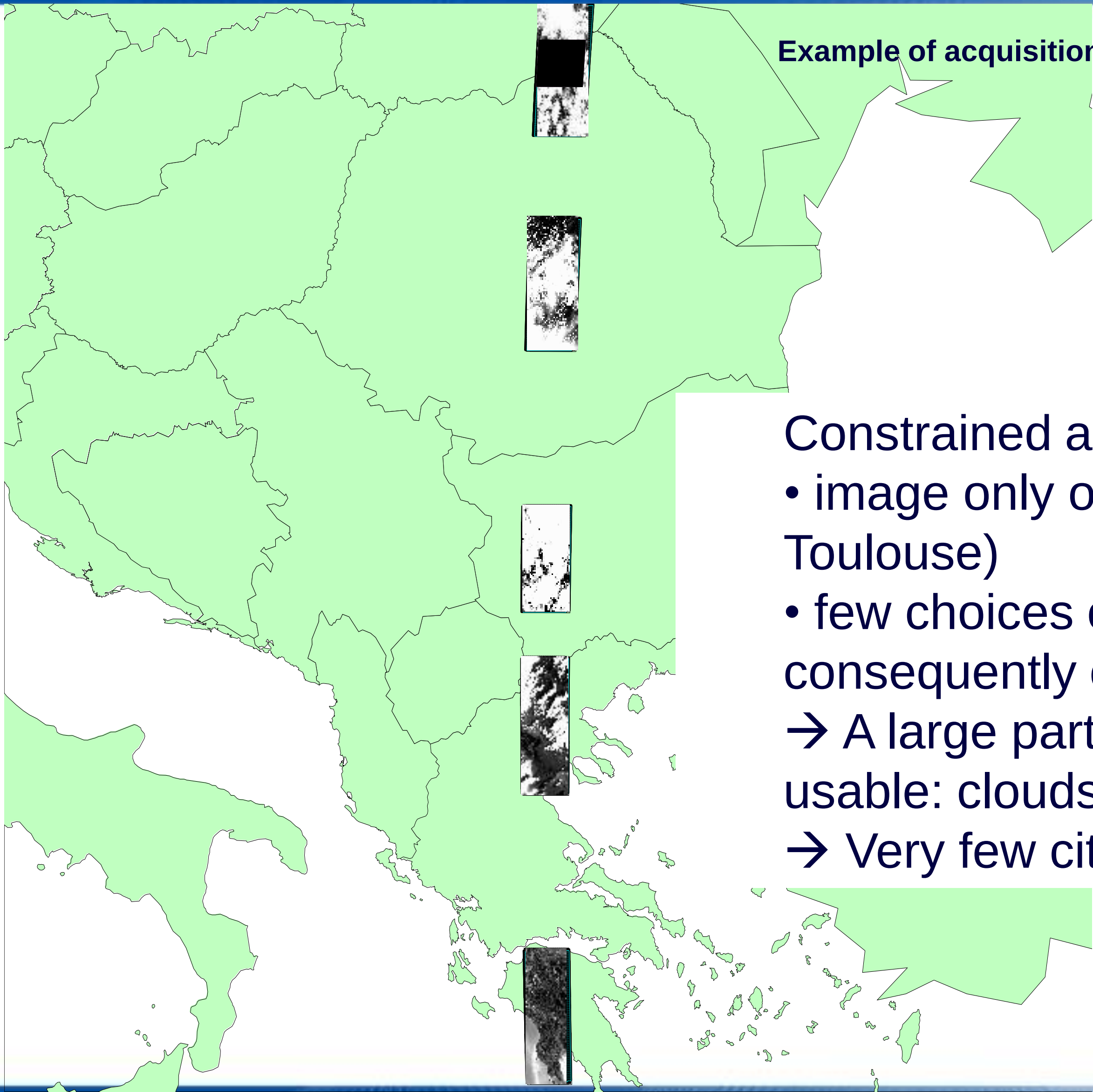
1. Applying the « Bad Extrapolation Detection » or visual assessment to determine the BFP zone
2. Applying the NN method using symmetric effects:
   - Learning phase on one side of the BFP
   - Testing phase on the other side
3. Determining uncertainty evaluation by repeating step 2

Tests made on SPOT2 (HRV2 camera) before de-orbiting:

→ We could use focusing mechanism over its whole range without endangered the mission

→ We used the reference method to compare the results with neural network method

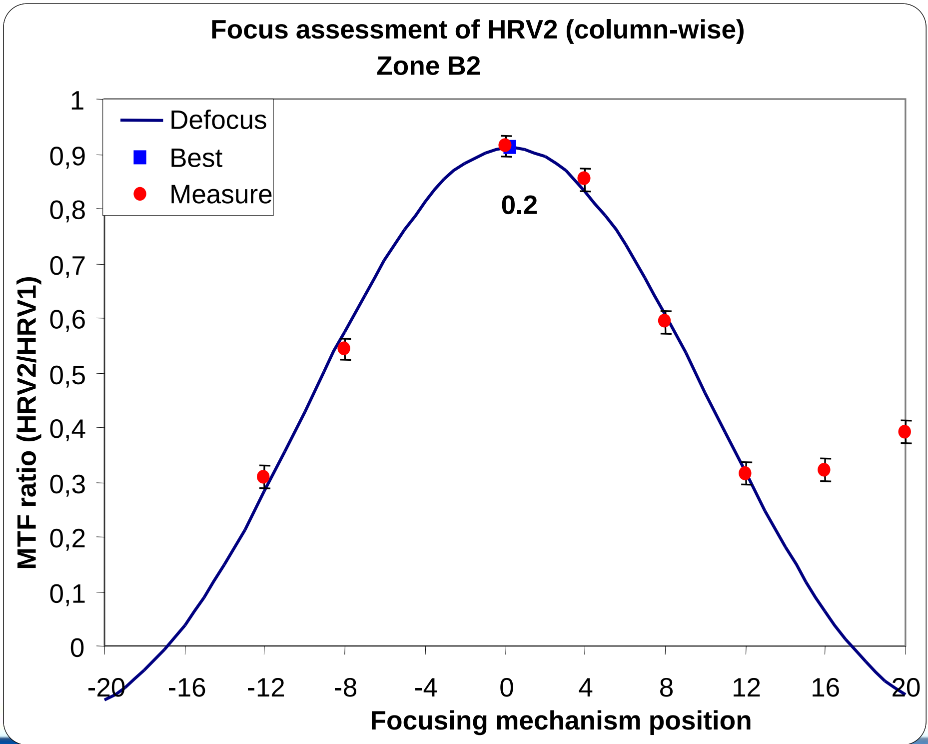
Test on SPOT2 : programming

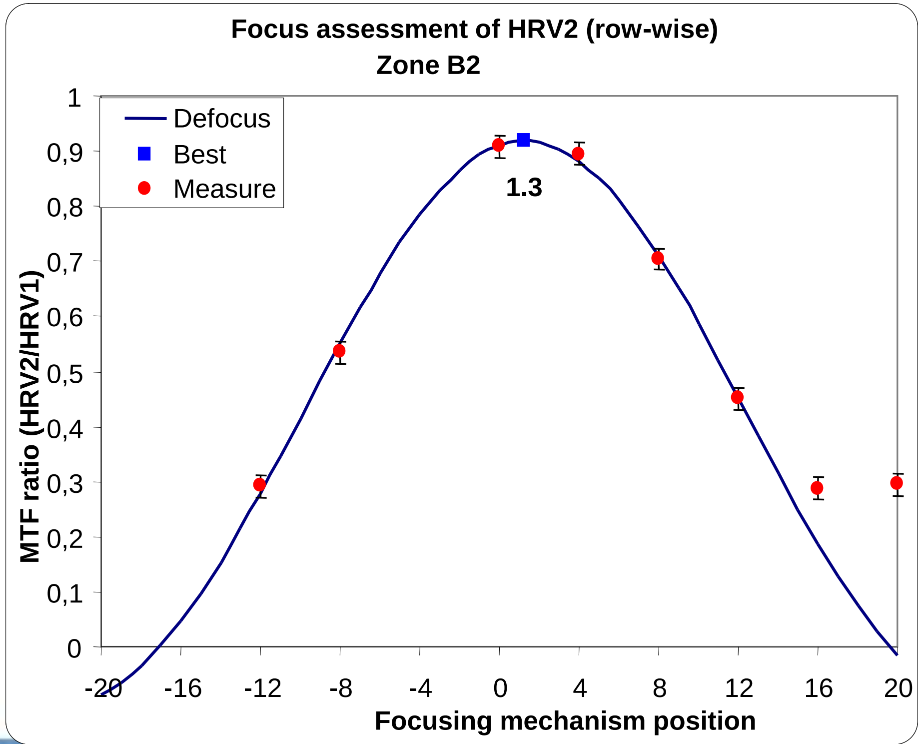


Constrained acquisitions:
• image only on Europe (visibility from Toulouse)
• few choices on the date and consequently on weather conditions
→ A large part of the images were not usable: clouds, sea
→ Very few cities and a lot of rural scenes

Defocus assessment on SPOT2: reference method

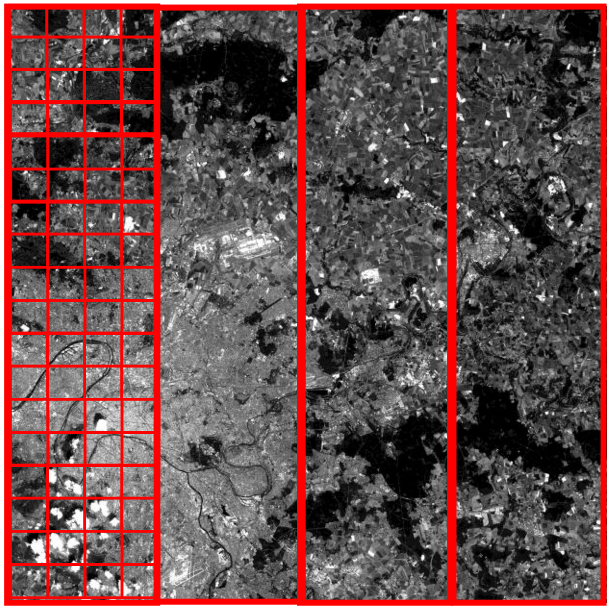
- Calculation of the MTF ratio between cameras HRV2 and HRV1
  - Frequency domain [0.25 fe – 0.35 fe]
- Defocus model fitted on measurement positions
  - p_0-12, p_0-8, p_0, p_0+4, p_0+8, p_0+12 → Good fitting
- Best focus plane position
  - Column p_m = 0.2
  - Row p_m = 1.3





ONERA

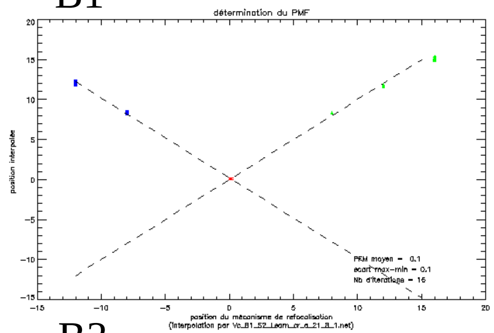
Defocus assessment on SPOT2: NN method



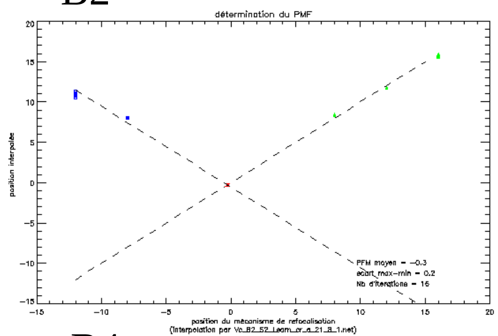
B1 B2 B3 B4

- We define 4 stripes on the image that correspond to the 4 sensor arrays
- We cut each zones into 128x128 images
- We calculate the associated features and place them into the pattern entry file of Neural Network (learning base or test base)

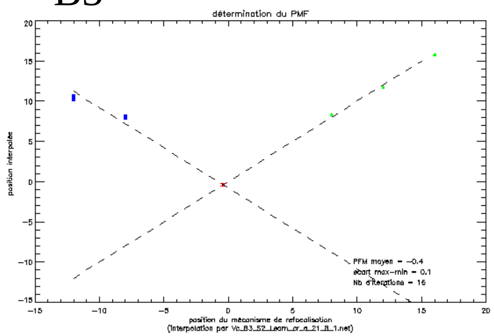
B1



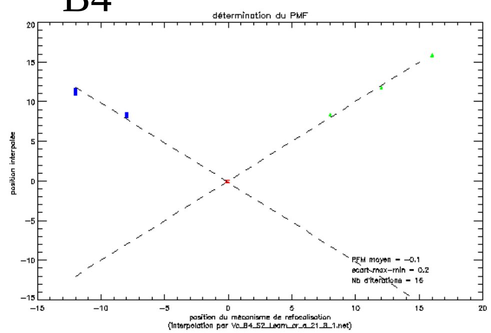
B2



B3

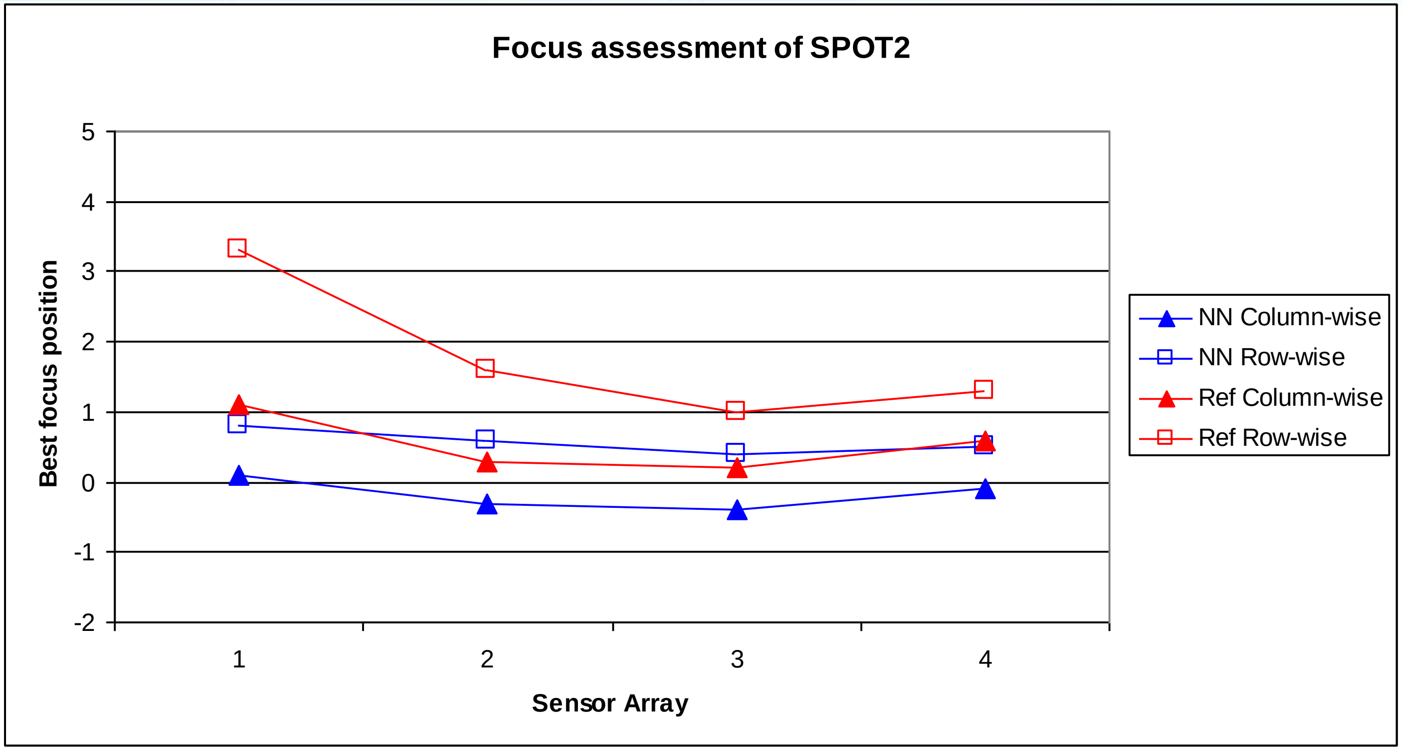


B4



→ Best Focus assessment for each zones column-wise and row-wise

Results Comparison



Neural method

	B1	B2	B3	B4
L	0.8	0.6	0.4	0.5
C	0.1	-0.3	-0.4	-0.1

Reference method

	B1	B2	B3	B4
L	3.3	1.6	1.0	1.8
C	1.1	0.3	0.2	0.6

Good agreement: mean deviation is 1 step,
standard deviation for each method is about 1 step

Summary

- Neural Network Defocus Assessment Method is a good alternative method to standard one
- It is easy and fast to operate
- It does not need any reference nor specific images

- The efficiency of method was demonstrated on actual images of SPOT2 in severe operating conditions
- Good agreement was found with the reference method
- Uncertainty has been evaluated to be better than 1 focusing step

→ uncertainty on MTF~ 0.005

Thanks to CNES who founded a part of this work

On-orbit MTF assessment of satellite cameras, D.Léger, F. Viallefont, Ph. Déliot (ONERA) and C. Valorge (CNES), Post-Launch Calibration of Satellite Sensors, ISPRS 2004